JPL

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

TPF Formation Acquisition Sensor Testbed

Jeff Tien, George Purcell, Jeff Srinivasan, Larry Young

Jet Propulsion Laboratory
California Institute of Technology

2003 TPF Expo
Pasadena, CA

Purpose of the FST Acquisition Sensor Testbeds

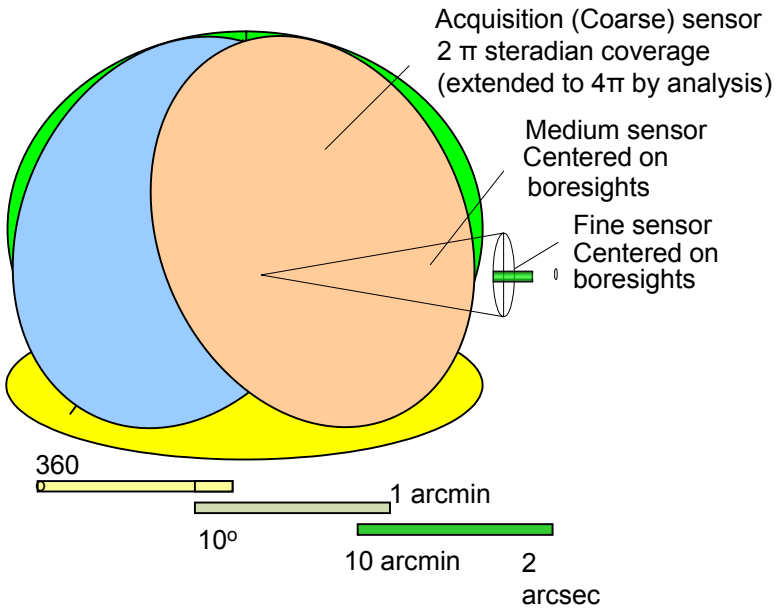
Terrestrial Planet Finder Mission

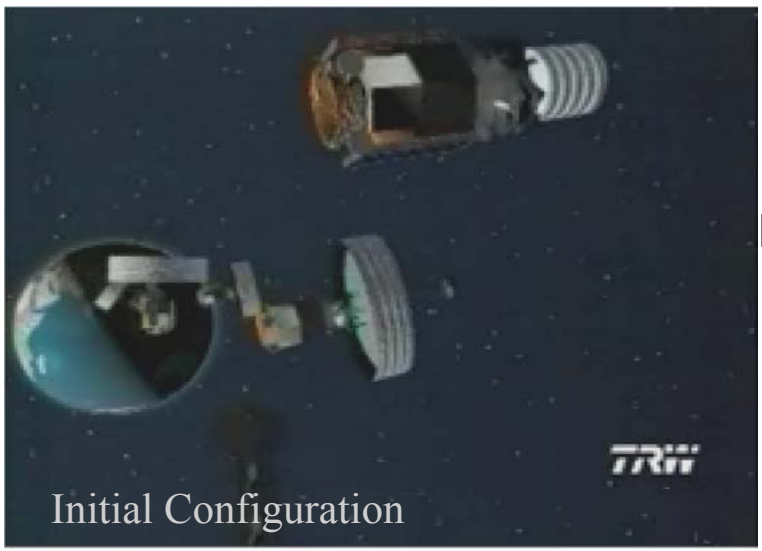
TPF

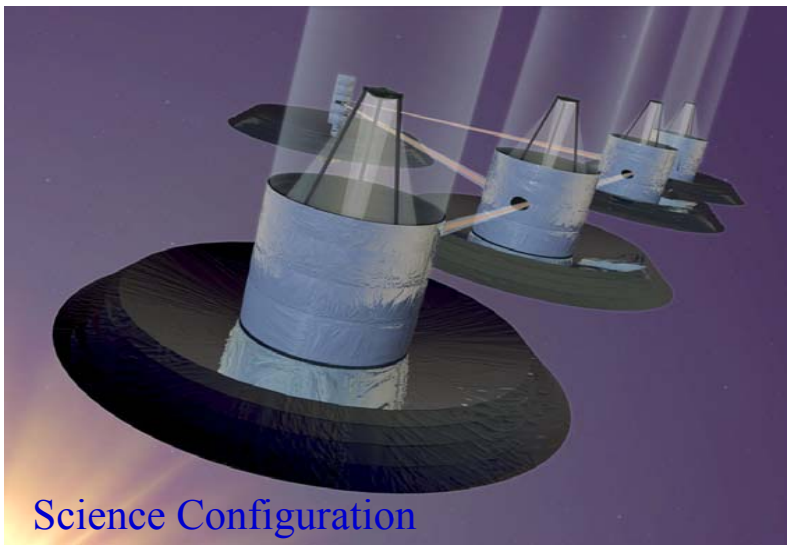
A NASA Origins Mission

To demonstrate feasibility of an integrated 4π-coverage range and bearing formation acquisition (coarse) sensor that would enables the spacecraft to perform:

- Lost-in-space recovery
- Coarse formation flying
- Collision avoidance in case of single spacecraft fault condition







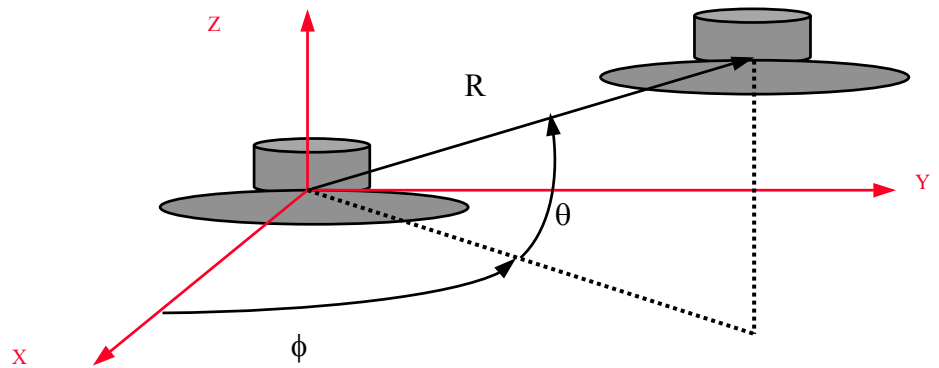
TPF Formation Sensor Testbed Requirements

Terrestrial Planet Finder Mission

TPF

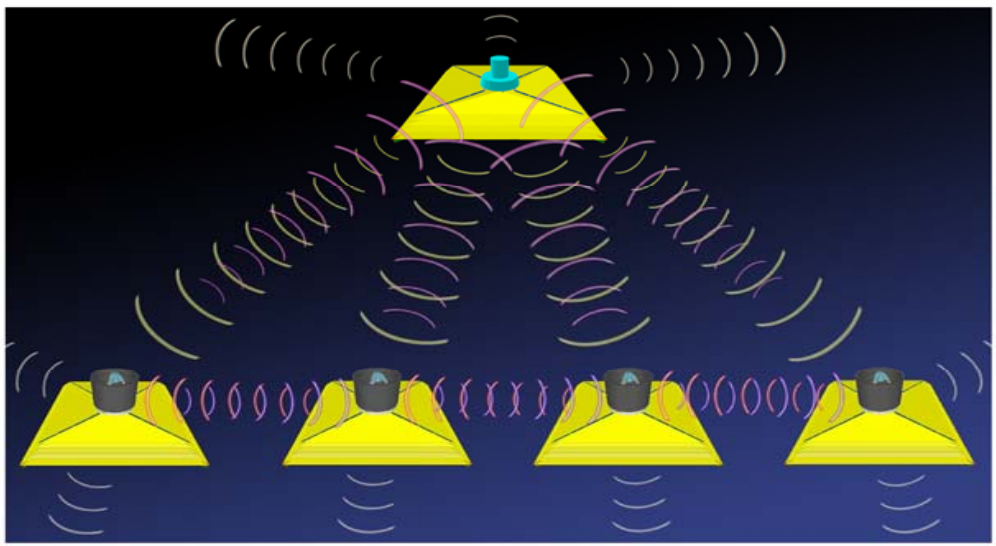
A NASA Origins Mission

Formation Sensor Testbed (FST)			
Requirements	**TPF Flight**	**FST**	**Comments**
Performance			
FOV Coverage	4 π sr	2 π sr	Extend to 4š by analysis
Cooperative Mode			
Operating Range	16 m - 10 km	16 m - 1 km	10 km for evaporation
Range Accuracy	0.5 m	0.5 m	
Bearing Accuracy	1 degree	1 degree	
Non-cooperative mode			**Radar mode**
Operating Range	16–200 m	16–50 m	center to center
Range Accuracy	1 m	4 m	
Bearing Accuracy	30 degrees	-	
Update Rate	1 Hz	1 Hz	



Assumptions for Relative-Sensor Requirements

- 5 spacecraft (scalable)
- Each spacecraft must be able to determine the range and bearing of any other visible spacecraft without prior information.
- Coarse sensor must be able to perform self-calibration without maneuvering the spacecraft.
- The coarse sensor must maintain the integrity of the formation in case of a fault condition (“radar mode”)



)()()()(
Range and Bearing-angle Links

Design and Features

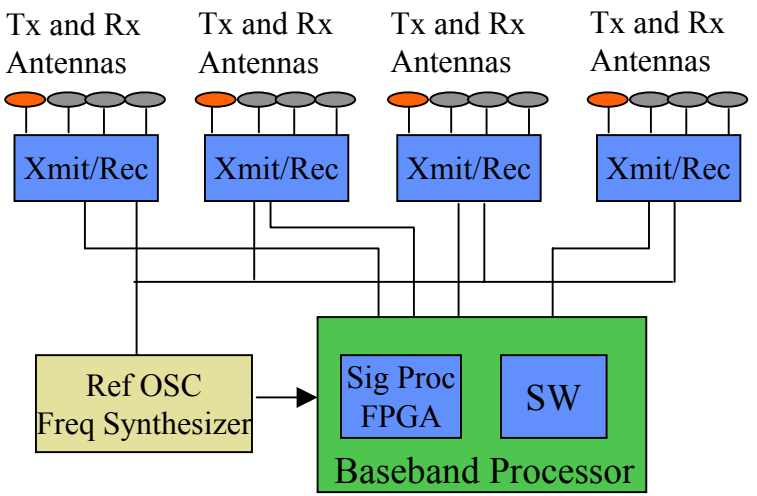
Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

An RF sensor (S band) based upon the Autonomous Formation Flying (AFF) sensor

- Integrated range and bearing sensor
- RF sensor to achieve 4π-steradian coverage
- Multiple sets of transmitting and receiving antennas to do ranging and bearing-angle measurements for a target spacecraft in any direction
  - 1 transmitting antenna
  - 3 receiving antennas
- Configurable baseband processor can perform multiple functions
  - GPS-type signal processing
    - Pseudorange and phase measurements
  - Local diagnostics and estimation
  - Inter-spacecraft communication
- Integrated radar for collision avoidance



High-level functional block diagram

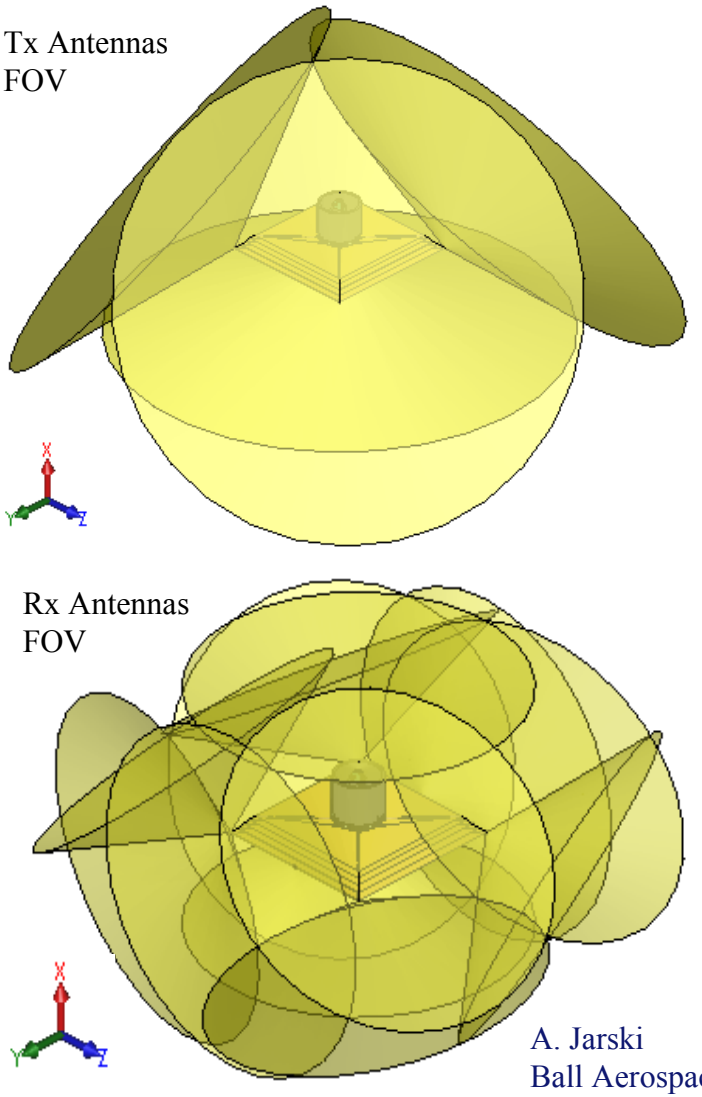
Design and Features

New signal structure and associated algorithms will be developed to enable:

- Simultaneous operation on many spacecraft.
- Fast signal acquisition of less than 1 minute for multiple spacecraft operation.
- An order of magnitude reduction of range error.
- Fine bearing angle measurement without the need for spacecraft rotation calibration maneuver.

Potential future capabilities

- Integrated high-rate comm.
- Integrated medium FF sensor



Technical Challenges

Terrestrial Planet Finder Mission

TPF

A NASA Origins Mission

Challenges	Mitigation			
	Analysis	Indoor Testbed	Outdoor Testbed	Other
• Achieve 4π coverage for both range and bearing measurements	√		√	√
• Calibrate the coarse sensor without spacecraft maneuvers	√	√	√	
• Perform adequate instrumental delay and phase calibration	√	√	√	
• Maintain the array with the coarse sensor disabled on one spacecraft (Radar mode)	√		√	
• Mitigate effect of multipath	√		√	√
• Acquire and track a combination of close and distant spacecraft	√	√	√	
• Meet requirement for heat dissipation on the cold side of the s/c	√			√
• Switch receiving and transmitting antennas dynamically	√		√	
• Frequency subsystem design	√	√	√	

Technical Challenge Mitigation Plan

Terrestrial Planet Finder Mission

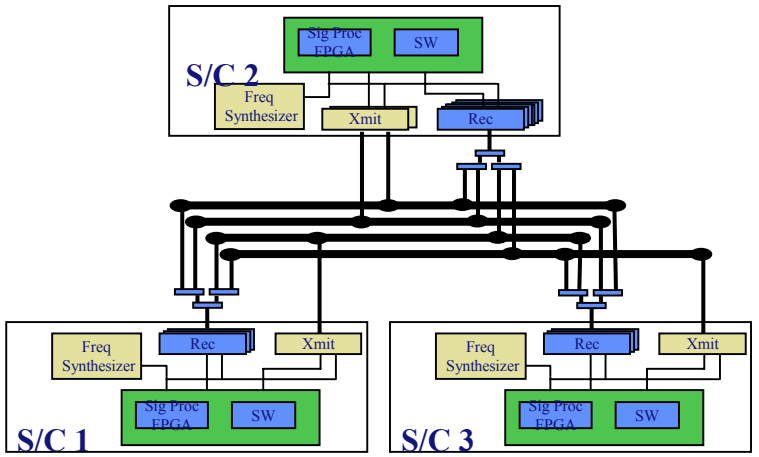
TPF

A NASA Origins Mission

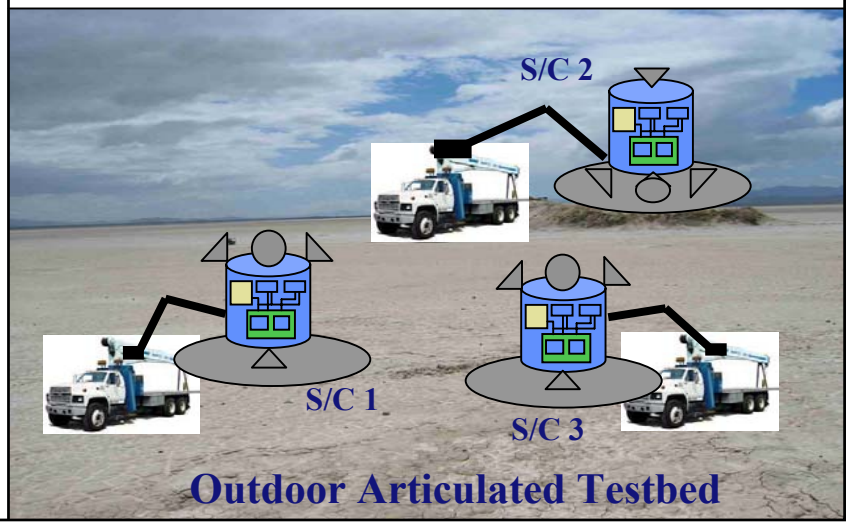
FST Acquisition Sensor Analysis

- Error Budget
  - Multipath
  - System noise
  - Link budget
  - Covariance analysis
- Signal acquisition analysis
- Frequency system analysis
- Antenna radiation & phase pattern modeling including the effect of s/c structure

FST Acquisition Sensor Testbeds



Indoor Functionality Testbed



Outdoor Articulated Testbed

Preliminary Test Result
(JPL Mesa 1200 ft range)

Terrestrial Planet Finder Mission

TPF

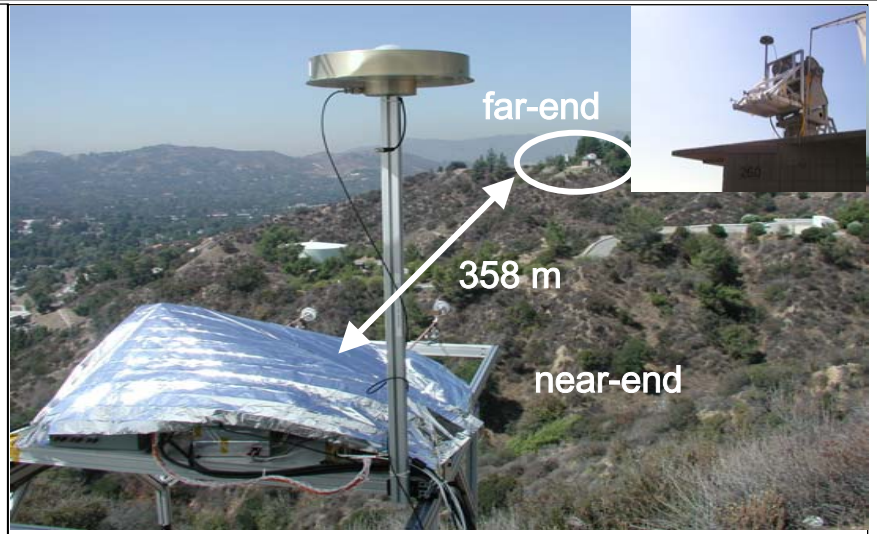
A NASA Origins Mission

Objective:

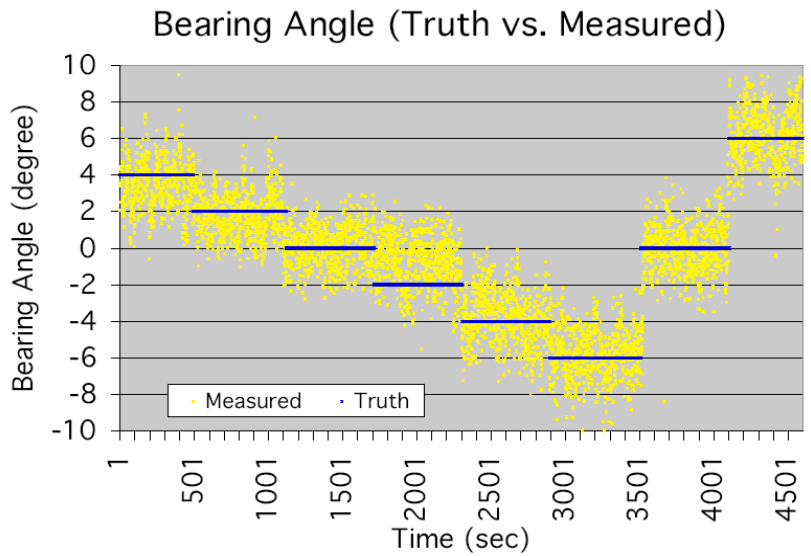
Proof-of-concept demo of using the simplified version of the new signal structure to get absolute bearing angle measurement without the need for spacecraft rotation calibration maneuver.

Requirement:

- Accuracy: < 5 degree bearing angle



JPL Mesa Antenna Test Range



Summary Results:

- Bearing accuracy: < 2 degrees
- Bearing precision: ~1 degree (1 σ)

Benefit for TPF:

- Significant reduction in flight system design and operational complexity.

Plans

Sept, 2004 - Demonstrate sensor functionality, range and bearing performance stability, and signal acquisition time for 2 s/c operation in the indoor testbed.

Sept, 2005 - Demonstrate sensor functionality, range and bearing performance stability (including jamming effect from the third s/c), and signal acquisition time for 3 s/c operation in the indoor testbed.

June, 2006 - Demonstrate end-to-end system performance and signal acquisition time for 3 s/c operation in the outdoor articulated testbed.

Acknowledgement

This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (Terrestrial Planet Finder project and Code R Distributed Spacecraft Technology program).